

CHAPTER 22 (Odd)

1. a. $E_\phi = E_L/\sqrt{3} = 208 \text{ V}/1.732 = 120.1 \text{ V}$ b. $V_\phi = E_\phi = 120.1 \text{ V}$
c. $I_\phi = \frac{V_\phi}{R_\phi} = \frac{120.1 \text{ V}}{10 \Omega} = 12.01 \text{ A}$ d. $I_L = I_\phi = 12.01 \text{ A}$
3. a. $E_\phi = 120.1 \text{ V}$ b. $V_\phi = 120.1 \text{ V}$
c. $Z_\phi = (10 \Omega \angle 0^\circ) \parallel (10 \Omega \angle -90^\circ) = 7.071 \Omega \angle -45^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{7.071 \Omega} = 16.98 \text{ A}$
d. $I_L = 16.98 \text{ A}$
5. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$
b. $V_{an} = 120 \text{ V} \angle 0^\circ, V_{bn} = 120 \text{ V} \angle -120^\circ, V_{cn} = 120 \text{ V} \angle 120^\circ$
c. $Z_\phi = 9 \Omega + j12 \Omega = 15 \Omega \angle 53.13^\circ$
 $I_{an} = \frac{120 \text{ V} \angle 0^\circ}{15 \Omega \angle 53.13^\circ} = 8 \text{ A} \angle -53.13^\circ, I_{bn} = \frac{120 \text{ V} \angle -120^\circ}{15 \Omega \angle 53.13^\circ} = 8 \text{ A} \angle -173.13^\circ$
 $I_{cn} = \frac{120 \text{ V} \angle 120^\circ}{15 \Omega \angle 53.13^\circ} = 8 \text{ A} \angle 66.87^\circ$
e. $I_L = I_\phi = 8 \text{ A}$ f. $E_L = \sqrt{3} E_\phi = (1.732)(120 \text{ V}) = 207.85 \text{ V}$
7. $V_\phi = V_{an} = V_{bn} = V_{cn} = \frac{V_L}{\sqrt{3}} = \frac{220 \text{ V}}{1.732} = 127.0 \text{ V}$
 $Z_\phi = 10 \Omega - j10 \Omega = 14.42 \Omega \angle -45^\circ$
 $I_\phi = I_{an} = I_{bn} = I_{cn} = \frac{V_\phi}{Z_\phi} = \frac{127 \text{ V}}{14.142 \Omega} = 8.98 \text{ A}$
 $I_L = I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = 8.98 \text{ A}$
9. a. $E_{AN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle -30^\circ = 12.7 \text{ kV} \angle -30^\circ$
 $E_{BN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle -150^\circ = 12.7 \text{ kV} \angle -150^\circ$
 $E_{CN} = \frac{22 \text{ kV}}{\sqrt{3}} \angle 90^\circ = 12.7 \text{ kV} \angle 90^\circ$

- b, c.
$$\begin{aligned} \mathbf{I}_{Aa} = \mathbf{I}_{an} &= \frac{\mathbf{E}_{AN}}{\mathbf{Z}_{AN}} = \frac{12.7 \text{ kV } \angle -30^\circ}{(30 \Omega + j40 \Omega) + (0.4 \text{ k}\Omega + j1 \text{ k}\Omega)} \\ &= \frac{12.7 \text{ kV } \angle -30^\circ}{430 \Omega + j1040 \Omega} = \frac{12.7 \text{ kV } \angle -30^\circ}{1125.39 \Omega \angle 67.54^\circ} \\ &= \mathbf{11.285 \text{ A } \angle -97.54^\circ} \end{aligned}$$
- $$\mathbf{I}_{Bb} = \mathbf{I}_{bn} = \frac{\mathbf{E}_{BN}}{\mathbf{Z}_{BN}} = \frac{12.7 \text{ kV } \angle -150^\circ}{1125.39 \Omega \angle 67.54^\circ} = \mathbf{11.285 \text{ A } \angle -217.54^\circ}$$
- $$\mathbf{I}_{Cc} = \mathbf{I}_{cn} = \frac{\mathbf{E}_{CN}}{\mathbf{Z}_{CN}} = \frac{12.7 \text{ kV } \angle 90^\circ}{1125.39 \Omega \angle 67.54^\circ} = \mathbf{11.285 \text{ A } \angle 22.46^\circ}$$
- d.
$$\begin{aligned} \mathbf{V}_{an} = \mathbf{I}_{an} \mathbf{Z}_{an} &= (11.285 \text{ A } \angle -97.54^\circ)(400 + j1000) \\ &= (11.285 \text{ A } \angle -97.54^\circ)(1077.03 \Omega \angle 68.2^\circ) \\ &= \mathbf{12,154.28 \text{ V } \angle -29.34^\circ} \end{aligned}$$
- $$\begin{aligned} \mathbf{V}_{bn} = \mathbf{I}_{bn} \mathbf{Z}_{bn} &= (11.285 \text{ A } \angle -217.54^\circ)(1077.03 \Omega \angle 68.2^\circ) \\ &= \mathbf{12,154.28 \text{ V } \angle -149.34^\circ} \end{aligned}$$
- $$\begin{aligned} \mathbf{V}_{cn} = \mathbf{I}_{cn} \mathbf{Z}_{cn} &= (11.285 \text{ A } \angle 22.46^\circ)(1077.03 \Omega \angle 68.2^\circ) \\ &= \mathbf{12,154.28 \text{ V } \angle 90.66^\circ} \end{aligned}$$
11. a.
$$E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$$
- b.
$$V_\phi = E_L = \mathbf{208 \text{ V}}$$
- c.
$$\mathbf{Z}_\phi = 6.8 \Omega + j14 \Omega = 15.564 \Omega \angle 64.09^\circ}$$
- $$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \text{ V}}{15.564 \Omega} = \mathbf{13.364 \text{ A}}$$
- d.
$$I_L = \sqrt{3} I_\phi = (1.732)(13.364 \text{ A}) = \mathbf{23.15 \text{ A}}$$
13. a.
$$\theta_2 = -120^\circ, \theta_3 = +120^\circ$$
- b.
$$\mathbf{V}_{ab} = 208 \text{ V } \angle 0^\circ, \mathbf{V}_{bc} = 208 \text{ V } \angle -120^\circ, \mathbf{V}_{ca} = 208 \text{ V } \angle 120^\circ}$$
- c. —
- d.
$$\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{208 \text{ V } \angle 0^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.455 \text{ A } \angle 0^\circ}$$
- $$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{208 \text{ V } \angle -120^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.455 \text{ A } \angle -120^\circ}$$
- $$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{208 \text{ V } \angle 120^\circ}{22 \Omega \angle 0^\circ} = \mathbf{9.455 \text{ A } \angle 120^\circ}$$
- e.
$$I_L = \sqrt{3} I_\phi = (1.732)(9.455 \text{ A}) = \mathbf{16.376 \text{ A}}$$
- f.
$$E_\phi = E_L / \sqrt{3} = 208 \text{ V} / 1.732 = \mathbf{120.1 \text{ V}}$$
15. a, b. The same as problem 12.
- c. —

$$d. \quad Z_{\phi} = 3 \, \Omega \angle 0^{\circ} \parallel 4 \, \Omega \angle 90^{\circ} = 2.4 \, \Omega \angle 36.87^{\circ}$$

$$I_{ab} = \frac{V_{ab}}{Z_{ab}} = \frac{208 \, V \angle 0^{\circ}}{2.4 \, \Omega \angle 36.87^{\circ}} = 86.67 \, A \angle -36.87^{\circ}$$

$$I_{bc} = \frac{V_{bc}}{Z_{bc}} = \frac{208 \, V \angle -120^{\circ}}{2.4 \, \Omega \angle 36.87^{\circ}} = 86.67 \, A \angle -156.87^{\circ}$$

$$I_{ca} = \frac{V_{ca}}{Z_{ca}} = \frac{208 \, V \angle 120^{\circ}}{2.4 \, \Omega \angle 36.87^{\circ}} = 86.67 \, A \angle 83.13^{\circ}$$

$$e. \quad I_L = \sqrt{3} I_{\phi} = (1.732)(86.67 \, A) = 150.11 \, A$$

$$f. \quad E_{\phi} = 120.1 \, V$$

$$17. \quad a. \quad I_{ab} = \frac{V_{ab}}{Z_{ab}} = \frac{16 \, kV \angle 0^{\circ}}{300 \, \Omega + j1000 \, \Omega} = \frac{16 \, kV \angle 0^{\circ}}{1044.03 \, \Omega \angle 73.30^{\circ}}$$

$$I_{ab} = 15.325 \, A \angle -73.30^{\circ}$$

$$I_{bc} = \frac{V_{bc}}{Z_{bc}} = \frac{16 \, kV \angle -120^{\circ}}{1044.03 \, \Omega \angle 73.30^{\circ}} = 15.325 \, A \angle -193.30^{\circ}$$

$$I_{ca} = \frac{V_{ca}}{Z_{ca}} = \frac{16 \, kV \angle 120^{\circ}}{1044.03 \, \Omega \angle 73.30^{\circ}} = 15.325 \, A \angle 46.7^{\circ}$$

$$b. \quad I_{Aa} - I_{ab} + I_{ca} = 0$$

$$I_{Aa} = I_{ab} - I_{ca} = 15.325 \, A \angle -73.30^{\circ} - 15.325 \, A \angle 46.7^{\circ}$$

$$= (4.40 \, A - j14.68 \, A) - (10.51 \, A + j11.153 \, A)$$

$$= 4.40 \, A - 10.51 \, A - j(14.68 \, A + 11.153 \, A)$$

$$= -6.11 \, A - j25.83 \, A = 26.54 \, A \angle -103.31^{\circ}$$

$$I_{Bb} + I_{ab} = I_{bc}$$

$$I_{Bb} = I_{bc} - I_{ab} = 15.325 \, A \angle -193.30^{\circ} - 15.325 \, A \angle -73.30^{\circ}$$

$$= 26.54 \, A \angle 136.68^{\circ}$$

$$I_{Cc} + I_{bc} = I_{ca}$$

$$I_{Cc} = I_{ca} - I_{bc} = 15.325 \, A \angle 46.7^{\circ} - 15.325 \, A \angle -193.30^{\circ}$$

$$= 26.54 \, A \angle 16.69^{\circ}$$

$$c. \quad E_{AB} = I_{Aa}(10 \, \Omega + j20 \, \Omega) + V_{ab} - I_{Bb}(22.361 \, \Omega \angle 63.43^{\circ})$$

$$= (26.54 \, A \angle -103.31^{\circ})(22.361 \, \Omega \angle 63.43^{\circ}) + 16 \, kV \angle 0^{\circ}$$

$$- (26.54 \, A \angle 136.68^{\circ})(22.361 \, \Omega \angle 63.43^{\circ})$$

$$= (455.41 \, V - j380.52 \, V) + 16,000 \, V - (-557.28 \, V - j204.04 \, V)$$

$$= 17,012.69 \, V - j176.48 \, V$$

$$= 17,013.6 \, V \angle -0.59^{\circ}$$

$$E_{BC} = I_{Bb}(22.361 \, \Omega \angle 63.43^{\circ}) + V_{bc} - I_{Cc}(22.361 \, \Omega \angle 63.53^{\circ})$$

$$= (26.54 \, A \angle 136.68^{\circ})(22.361 \, \Omega \angle 63.53^{\circ}) + 16 \, kV \angle -120^{\circ}$$

$$- (26.54 \, A \angle 16.69^{\circ})(22.361 \, \Omega \angle 63.53^{\circ})$$

$$= -8659.07 \, V - j14,645.44 \, V$$

$$= 17,013.77 \, V \angle -120.59^{\circ}$$

$$\begin{aligned}
\mathbf{E}_{CA} &= \mathbf{I}_{Cc}(22.361 \Omega \angle 63.43^\circ) + \mathbf{V}_{ca} - \mathbf{I}_{Aa}(22.361 \Omega \angle 63.43^\circ) \\
&= (26.54 \text{ A} \angle 16.69^\circ)(22.361 \Omega \angle 63.43^\circ) + 16,000 \text{ V} \angle +120^\circ \\
&\quad - (26.54 \text{ A} \angle -103.31^\circ)(22.361 \Omega \angle 63.53^\circ) \\
&= -8355.27 \text{ V} + j14,820.97 \text{ V} \\
&= \mathbf{17,013.87 \text{ V} \angle 119.41^\circ}
\end{aligned}$$

19. a. $E_\phi = E_L = \mathbf{208 \text{ V}}$

b. $V_\phi = E_L \sqrt{3} = \mathbf{120.09 \text{ V}}$

c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.09 \text{ V}}{16.971 \Omega} = \mathbf{7.076 \text{ A}}$

d. $I_L = I_\phi = \mathbf{7.076 \text{ A}}$

21. $V_{an} = V_{bn} = V_{cn} = \frac{120 \text{ V}}{\sqrt{3}} = \frac{120 \text{ V}}{1.732} = \mathbf{69.28 \text{ V}}$

$$I_{an} = I_{bn} = I_{cn} = \frac{69.28 \text{ V}}{24 \Omega} = \mathbf{2.89 \text{ A}}$$

$$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{2.89 \text{ A}}$$

23. $V_{an} = V_{bn} = V_{cn} = \mathbf{69.28 \text{ V}}$

$$\mathbf{Z}_\phi = 20 \Omega \angle 0^\circ \parallel 15 \Omega \angle -90^\circ = 12 \Omega \angle -53.13^\circ$$

$$I_{an} = I_{bn} = I_{cn} = \frac{69.28 \text{ V}}{12 \Omega} = \mathbf{5.77 \text{ A}}$$

$$I_{Aa} = I_{Bb} = I_{Cc} = \mathbf{5.77 \text{ A}}$$

25. a. $E_\phi = E_L = \mathbf{440 \text{ V}}$

b. $V_\phi = E_L = \mathbf{440 \text{ V}}$

c. $\mathbf{Z}_\phi = 12 \Omega - j9 \Omega = 15 \Omega \angle -36.87^\circ$

$$I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{15 \Omega} = \mathbf{29.33 \text{ A}}$$

d. $I_L = \sqrt{3} I_\phi = (1.732)(29.33 \text{ A}) = \mathbf{50.8 \text{ A}}$

27. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$

b. $\mathbf{V}_{ab} = 100 \text{ V} \angle 0^\circ, \mathbf{V}_{bc} = 100 \text{ V} \angle -120^\circ, \mathbf{V}_{ca} = 100 \text{ V} \angle 120^\circ$

c. —

d. $\mathbf{I}_{ab} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_{ab}} = \frac{100 \text{ V} \angle 0^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle 0^\circ}$

$$\mathbf{I}_{bc} = \frac{\mathbf{V}_{bc}}{\mathbf{Z}_{bc}} = \frac{100 \text{ V} \angle -120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle -120^\circ}$$

$$\mathbf{I}_{ca} = \frac{\mathbf{V}_{ca}}{\mathbf{Z}_{ca}} = \frac{100 \text{ V} \angle 120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{5 \text{ A} \angle 120^\circ}$$

e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3} (5 \text{ A}) = \mathbf{8.66 \text{ A}}$

29. a. $\theta_2 = -120^\circ, \theta_3 = 120^\circ$
- b. $V_{ab} = 100 \text{ V } \angle 0^\circ, V_{bc} = 100 \text{ V } \angle -120^\circ, V_{ca} = 100 \text{ V } \angle 120^\circ$
- c. —
- d. $Z_\phi = 20 \Omega \angle 0^\circ \parallel 20 \Omega \angle -90^\circ = 14.14 \Omega \angle -45^\circ$
- $$I_{ab} = \frac{100 \text{ V } \angle 0^\circ}{14.14 \Omega \angle -45^\circ} = 7.072 \text{ A } \angle 45^\circ$$
- $$I_{bc} = \frac{100 \text{ V } \angle -120^\circ}{14.14 \Omega \angle -45^\circ} = 7.072 \text{ A } \angle -75^\circ$$
- $$I_{ca} = \frac{100 \text{ V } \angle 120^\circ}{14.14 \Omega \angle -45^\circ} = 7.072 \text{ A } \angle 165^\circ$$
- e. $I_{Aa} = I_{Bb} = I_{Cc} = (\sqrt{3})(7.072 \text{ A}) = 12.25 \text{ A}$

31. $V_\phi = 120 \text{ V}, I_\phi = 120 \text{ V}/20 \Omega = 6 \text{ A}$

$$P_T = 3I_\phi^2 R_\phi = 3(6 \text{ A})^2 20 \Omega = 2160 \text{ W}$$

$$Q_T = 0 \text{ VAR}$$

$$S_T = P_T = 2160 \text{ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{2160 \text{ W}}{2160 \text{ VA}} = 1$$

33. $V_\phi = 208 \text{ V}$

$$P_T = 3 \left[\frac{V_\phi^2}{R_\phi} \right] = 3 \cdot \frac{(208 \text{ V})^2}{18 \Omega} = 7210.67 \text{ W}$$

$$Q_T = 3 \left[\frac{V_\phi^2}{X_\phi} \right] = 3 \cdot \frac{(208 \text{ V})^2}{18 \Omega} = 7210.67 \text{ VAR}(C)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 10,197.42 \text{ VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{7210.67 \text{ W}}{10,197.42 \text{ VA}} = 0.707 \text{ (leading)}$$

35. $P_T = 3I_\phi^2 R_\phi = 3(15.56 \text{ A})^2 10 \Omega = 7.263 \text{ kW}$

$$Q_T = 3I_\phi^2 X_\phi = 3(15.56 \text{ A})^2 10 \Omega = 7.263 \text{ kVAR}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 10.272 \text{ kVA}$$

$$F_p = \frac{P_T}{S_T} = \frac{7.263 \text{ kW}}{10.272 \text{ kVA}} = 0.7071 \text{ (lagging)}$$

$$37. \quad Z_{\phi} = 10 \, \Omega + j20 \, \Omega = 22.36 \, \Omega \angle 63.43^{\circ}$$

$$V_{\phi} = \frac{V_L}{\sqrt{3}} = \frac{120 \, \text{V}}{1.732} = 69.28 \, \text{V}$$

$$I_{\phi} = \frac{V_{\phi}}{Z_{\phi}} = \frac{69.28 \, \text{V}}{22.36 \, \Omega} = 3.098 \, \text{A}$$

$$P_T = 3I_{\phi}^2 R_{\phi} = 3(3.098 \, \text{A})^2 10 \, \Omega = 287.93 \, \text{W}$$

$$Q_T = 3I_{\phi}^2 X_{\phi} = 3(3.098 \, \text{A})^2 20 \, \Omega = 575.86 \, \text{VAR}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 643.83 \, \text{VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{287.93 \, \text{W}}{643.83 \, \text{VA}} = 0.4472 \, (\text{lagging})$$

$$39. \quad Z_{\phi} = 12 \, \Omega + j16 \, \Omega = 20 \, \Omega \angle 53.13^{\circ}$$

$$I_{\phi} = \frac{V_{\phi}}{Z_{\phi}} = \frac{100 \, \text{V}}{20 \, \Omega} = 5 \, \text{A}$$

$$P_T = 3I_{\phi}^2 R_{\phi} = 3(5 \, \text{A})^2 12 \, \Omega = 900 \, \text{W}$$

$$Q_T = 3I_{\phi}^2 X_{\phi} = 3(5 \, \text{A})^2 16 \, \Omega = 1200 \, \text{VAR}(L)$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = 1500 \, \text{VA}$$

$$F_p = \frac{P_T}{S_T} = \frac{900 \, \text{W}}{1500 \, \text{VA}} = 0.6 \, (\text{lagging})$$

$$41. \quad P_T = \sqrt{3} E_L I_L \cos \theta$$

$$1200 \, \text{W} = \sqrt{3} (208 \, \text{V}) I_L (0.6) \Rightarrow I_L = 5.55 \, \text{A}$$

$$V_{\phi} = \frac{V_L}{\sqrt{3}} = \frac{208 \, \text{V}}{1.732} = 120.1 \, \text{V}$$

$$\theta = \cos^{-1} 0.6 = 53.13^{\circ} \, (\text{leading})$$

$$Z_{\phi} = \frac{V_{\phi}}{I_{\phi}} = \frac{120.1 \, \text{V} \angle 0^{\circ}}{5.55 \, \text{A} \angle 53.13^{\circ}} = 21.64 \, \Omega \angle -53.13^{\circ} = \underbrace{12.98 \, \Omega}_R - j \underbrace{17.31 \, \Omega}_{X_C}$$

$$43. \quad \text{a.} \quad E_{\phi} = \frac{16 \, \text{kV}}{\sqrt{3}} = 9,237.6 \, \text{V}$$

$$\text{b.} \quad I_L = I_{\phi} = 80 \, \text{A}$$

$$\text{c.} \quad P_{\phi_L} = \frac{1200 \, \text{kW}}{3} = 400 \, \text{kW}$$

$$P_{4\Omega} = (80 \, \text{A})^2 4 \, \Omega = 25.6 \, \text{kW}$$

$$P_T = 3P_{\phi} = 3(25.6 \, \text{kW} + 400 \, \text{kW}) = 1276.8 \, \text{kW}$$

$$\text{d.} \quad F_p = \frac{P_T}{S_T}, \quad S_T = \sqrt{3} V_L I_L = \sqrt{3} (16 \, \text{kV})(80 \, \text{A}) = 2,217.025 \, \text{kVA}$$

$$F_p = \frac{1,276.8 \, \text{kW}}{2,217.025 \, \text{kVA}} = 0.576 \, \text{lagging}$$

$$e. \quad \theta_L = \cos^{-1} 0.576 = 54.83^\circ \text{ (lagging)}$$

$$\mathbf{I}_{Aa} = \frac{\mathbf{E}_{AN} \angle 0^\circ}{\mathbf{Z}_T \angle 54.83^\circ} \Rightarrow \underbrace{80 \text{ A} \angle -54.83^\circ}_{\substack{\uparrow \\ \text{for entire load}}}$$

$$\begin{aligned} f. \quad \mathbf{V}_{an} &= \mathbf{E}_{AN} - \mathbf{I}_{Aa}(4 \Omega + j20 \Omega) \\ &= 9237.6 \text{ V} \angle 0^\circ - (80 \text{ A} \angle -54.83^\circ)(20.396 \Omega \angle 78.69^\circ) \\ &= 9237.6 \text{ V} \angle 0^\circ - 1631.68 \text{ V} \angle 23.86^\circ \\ &= 9237.6 \text{ V} - (1492.22 \text{ V} + j660 \text{ V}) \\ &= 7745.38 \text{ V} - j660 \text{ V} \\ &= \mathbf{7773.45 \text{ V} \angle -4.87^\circ} \end{aligned}$$

$$\begin{aligned} g. \quad \mathbf{Z}_\phi &= \frac{\mathbf{V}_{an}}{\mathbf{I}_{Aa}} = \frac{7773.45 \text{ V} \angle -4.87^\circ}{80 \text{ A} \angle -54.83^\circ} = 97.168 \Omega \angle 49.95^\circ \\ &= \underbrace{62.52 \Omega}_R + j\underbrace{74.38 \Omega}_{X_L} \end{aligned}$$

$$\begin{aligned} h. \quad F_p(\text{entire load}) &= \mathbf{0.576 \text{ (lagging)}} \\ F_p(\text{load}) &= \mathbf{0.643 \text{ (lagging)}} \end{aligned}$$

$$i. \quad \eta = \frac{P_o}{P_i} = \frac{P_i - P_{\text{lost}}}{P_i} = \frac{1276.8 \text{ kW} - 3(25.6 \text{ kW})}{1276.8 \text{ kW}} = 0.9398 \Rightarrow \mathbf{93.98\%}$$

$$45. \quad b. \quad P_T = \mathbf{5899.64 \text{ W}}, P_{\text{meter}} = \mathbf{1966.55 \text{ W}}$$

$$49. \quad a. \quad V_\phi = E_\phi = \frac{E_L}{\sqrt{3}} = \mathbf{120.09 \text{ V}}$$

$$\begin{aligned} b. \quad I_{an} &= \frac{V_{an}}{Z_{an}} = \frac{120.09 \text{ V}}{14.142 \Omega} = \mathbf{8.492 \text{ A}} \\ I_{bn} &= \frac{V_{bn}}{Z_{bn}} = \frac{120.09 \text{ V}}{16.971 \Omega} = \mathbf{7.076 \text{ A}} \\ I_{cn} &= \frac{V_{cn}}{Z_{cn}} = \frac{120.09 \text{ V}}{2.828 \Omega} = \mathbf{42.465 \text{ A}} \end{aligned}$$

$$\begin{aligned} c. \quad P_T &= I_{an}^2 10 \Omega + I_{bn}^2 12 \Omega + I_{cn}^2 2 \Omega \\ &= (8.492 \text{ A})^2 10 \Omega + (7.076 \text{ A})^2 12 \Omega + (42.465 \text{ A})^2 2 \Omega \\ &= 721.141 \text{ W} + 600.837 \text{ W} + 3606.552 \text{ W} \\ &= \mathbf{4928.53 \text{ W}} \end{aligned}$$

$$Q_T = P_T = \mathbf{4928.53 \text{ VAR(L)}}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{6969.99 \text{ VA}}$$

$$F_p = \frac{P_T}{S_T} = \mathbf{0.7071 \text{ (lagging)}}$$

$$d. \quad \mathbf{E}_{an} = 120.09 \text{ V} \angle -30^\circ, \mathbf{E}_{bn} = 120.09 \text{ V} \angle -150^\circ, \mathbf{E}_{cn} = 120.09 \text{ V} \angle 90^\circ$$

$$\mathbf{I}_{an} = \frac{\mathbf{E}_{an}}{\mathbf{Z}_{an}} = \frac{120.09 \text{ V} \angle -30^\circ}{10 \Omega + j10 \Omega} = \frac{120.09 \text{ V} \angle -30^\circ}{14.142 \Omega \angle 45^\circ} = 8.492 \text{ A} \angle -75^\circ$$

$$\mathbf{I}_{bn} = \frac{\mathbf{E}_{bn}}{\mathbf{Z}_{bn}} = \frac{120.09 \text{ V} \angle -150^\circ}{12 \Omega + j12 \Omega} = \frac{120.09 \text{ V} \angle -150^\circ}{16.971 \Omega \angle 45^\circ} = 7.076 \text{ A} \angle -195^\circ$$

$$\mathbf{I}_{cn} = \frac{\mathbf{E}_{cn}}{\mathbf{Z}_{cn}} = \frac{120.09 \text{ V} \angle 90^\circ}{2 \Omega + j2 \Omega} = \frac{120.09 \text{ V} \angle 90^\circ}{2.828 \Omega \angle 45^\circ} = 42.465 \text{ A} \angle 45^\circ$$

$$\begin{aligned} e. \quad \mathbf{I}_N &= \mathbf{I}_{an} + \mathbf{I}_{bn} + \mathbf{I}_{cn} \\ &= 8.492 \text{ A} \angle -75^\circ + 7.076 \text{ A} \angle -195^\circ + 42.465 \text{ A} \angle 45^\circ \\ &= (2.198 \text{ A} - j8.20 \text{ A}) + (-6.83 \text{ A} + j1.83 \text{ A}) + (30.03 \text{ A} + j30.03 \text{ A}) \\ &= 25.398 \text{ A} - j23.661 \text{ A} \\ &= 34.712 \text{ A} \angle -42.972^\circ \end{aligned}$$

CHAPTER 22 (Even)

2. a. $E_\phi = E_L/\sqrt{3} = 208 \text{ V}/1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_\phi = \mathbf{120.1 \text{ V}}$
 c. $Z_\phi = 12 \Omega - j16 \Omega = 20 \Omega \angle -53.13^\circ$ d. $I_L = I_\phi = \mathbf{6 \text{ A}}$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \text{ V}}{20 \Omega} \cong \mathbf{6 \text{ A}}$
4. a. $\theta_2 = -120^\circ, \theta_3 = 120^\circ$
 b. $V_{an} = 120 \text{ V} \angle 0^\circ, V_{bn} = 120 \text{ V} \angle -120^\circ, V_{cn} = 120 \text{ V} \angle 120^\circ$
 c. $I_{an} = \frac{V_{an}}{Z_{an}} = \frac{120 \text{ V} \angle 0^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle 0^\circ}$
 $I_{bn} = \frac{V_{bn}}{Z_{bn}} = \frac{120 \text{ V} \angle -120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle -120^\circ}$
 $I_{cn} = \frac{V_{cn}}{Z_{cn}} = \frac{120 \text{ V} \angle 120^\circ}{20 \Omega \angle 0^\circ} = \mathbf{6 \text{ A} \angle 120^\circ}$
 d. $I_L = I_\phi = \mathbf{6 \text{ A}}$ e. $V_L = \sqrt{3} V_\phi = \sqrt{3} (120 \text{ V}) = \mathbf{207.8 \text{ V}}$
6. a, b. The same as problem 4.
 c. $Z_\phi = 6 \Omega \angle 0^\circ \parallel 8 \Omega \angle -90^\circ = 4.8 \Omega \angle -36.87^\circ$
 $I_{an} = \frac{V_{an}}{Z_{an}} = \frac{120 \text{ V} \angle 0^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle 36.87^\circ}$
 $I_{bn} = \frac{V_{bn}}{Z_{bn}} = \frac{120 \text{ V} \angle -120^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle -83.13^\circ}$
 $I_{cn} = \frac{V_{cn}}{Z_{cn}} = \frac{120 \text{ V} \angle 120^\circ}{4.8 \Omega \angle -36.87^\circ} = \mathbf{25 \text{ A} \angle 156.87^\circ}$
 d. $I_L = I_\phi = \mathbf{25 \text{ A}}$ e. $V_L = \sqrt{3} V_\phi = \sqrt{3} (120 \text{ V}) = \mathbf{207.84 \text{ V}}$
8. $Z_\phi = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{50 \text{ V}}{20 \Omega} = \mathbf{2.5 \text{ A}}$
 $Z_{T_\phi} = 13 \Omega + j16 \Omega = 20.62 \Omega \angle 50.91^\circ$
 $V_\phi = I_\phi Z_{T_\phi} = (2.5 \text{ A})(20.62 \Omega) = 51.55 \text{ V}$
 $V_L = \sqrt{3} V_\phi = (\sqrt{3})(51.55 \text{ V}) = \mathbf{89.285 \text{ V}}$
10. a. $E_\phi = E_L/\sqrt{3} = 208 \text{ V}/1.732 = \mathbf{120.1 \text{ V}}$ b. $V_\phi = E_L = \mathbf{208 \text{ V}}$
 c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \text{ V}}{20 \Omega} = \mathbf{10.4 \text{ A}}$ d. $I_L = \sqrt{3} I_\phi = (1.732)(10.4 \text{ A}) = \mathbf{18 \text{ A}}$

$$12. \quad \mathbf{Z}_\phi = 18 \, \Omega \angle 0^\circ \parallel 18 \, \Omega \angle -90^\circ = 12.728 \, \Omega \angle -45^\circ$$

$$a. \quad E_\phi = V_L / \sqrt{3} = 208 \, \text{V} / \sqrt{3} = \mathbf{120.09 \, \text{V}} \quad b. \quad V_\phi = \mathbf{208 \, \text{V}}$$

$$c. \quad I_\phi = \frac{V_\phi}{Z_\phi} = \frac{208 \, \text{V}}{12.728 \, \Omega} = \mathbf{16.342 \, \text{A}}$$

$$d. \quad I_L = \sqrt{3} I_\phi = (1.732)(16.342 \, \text{A}) = \mathbf{28.304 \, \text{A}}$$

$$14. \quad a. \quad \theta_2 = -120^\circ, \theta_3 = +120^\circ$$

$$b. \quad \mathbf{V_{ab} = 208 \, \text{V} \angle 0^\circ, V_{bc} = 208 \, \text{V} \angle -120^\circ, V_{ca} = 208 \, \text{V} \angle 120^\circ}$$

$$c. \quad -$$

$$d. \quad \mathbf{Z_\phi = 100 \, \Omega - j100 \, \Omega = 141.42 \, \Omega \angle -45^\circ}$$

$$\mathbf{I_{ab} = \frac{V_{ab}}{Z_{ab}} = \frac{208 \, \text{V} \angle 0^\circ}{141.42 \, \Omega \angle -45^\circ} = 1.471 \, \text{A} \angle 45^\circ}$$

$$\mathbf{I_{bc} = \frac{V_{bc}}{Z_{bc}} = \frac{208 \, \text{V} \angle -120^\circ}{141.42 \, \Omega \angle -45^\circ} = 1.471 \, \text{A} \angle -75^\circ}$$

$$\mathbf{I_{ca} = \frac{V_{ca}}{Z_{ca}} = \frac{208 \, \text{V} \angle 120^\circ}{141.42 \, \Omega \angle -45^\circ} = 1.471 \, \text{A} \angle 165^\circ}$$

$$e. \quad I_L = \sqrt{3} I_\phi = (1.732)(1.471 \, \text{A}) = \mathbf{2.548 \, \text{A}}$$

$$f. \quad E_\phi = E_L / \sqrt{3} = 208 \, \text{V} / 1.732 = \mathbf{120.1 \, \text{V}}$$

$$16. \quad \mathbf{V_{ab} = V_{bc} = V_{ca} = 220 \, \text{V}}$$

$$\mathbf{Z_\phi = 10 \, \Omega + j10 \, \Omega = 14.142 \, \Omega \angle 45^\circ}$$

$$\mathbf{I_{ab} = I_{bc} = I_{ca} = \frac{V_\phi}{Z_\phi} = \frac{220 \, \text{V}}{14.142 \, \Omega} = 15.56 \, \text{A}}$$

$$18. \quad a. \quad E_\phi = E_L = \mathbf{208 \, \text{V}} \quad b. \quad V_\phi = \frac{E_L}{\sqrt{3}} = \frac{208 \, \text{V}}{1.732} = \mathbf{120.1 \, \text{V}}$$

$$c. \quad I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \, \text{V}}{30 \, \Omega} = \mathbf{4.003 \, \text{A}} \quad d. \quad I_L = I_\phi \cong \mathbf{4 \, \text{A}}$$

$$20. \quad a, b. \quad \text{The same as problem 18.}$$

$$c. \quad \mathbf{Z_\phi = 15 \, \Omega \angle 0^\circ \parallel 20 \, \Omega \angle -90^\circ = 12 \, \Omega \angle -36.87^\circ}$$

$$\mathbf{I_\phi = \frac{V_\phi}{Z_\phi} = \frac{120.1 \, \text{V}}{12 \, \Omega} \cong 10 \, \text{A}}$$

$$d. \quad \mathbf{I_L = I_\phi \cong 10 \, \text{A}}$$

22. $V_{an} = V_{bn} = V_{cn} = \frac{120 \text{ V}}{\sqrt{3}} = \mathbf{69.28 \text{ V}}$
 $Z_\phi = 10 \Omega + j20 \Omega = 22.36 \Omega \angle 63.43^\circ$
 $I_{an} = I_{bn} = I_{cn} = \frac{V_\phi}{Z_\phi} = \frac{69.28 \text{ V}}{22.36 \Omega} = \mathbf{3.098 \text{ A}}$
 $I_{Aa} = I_{Bb} = I_{Cc} = I_\phi = \mathbf{3.098 \text{ A}}$
24. a. $E_\phi = E_L = \mathbf{440 \text{ V}}$ b. $V_\phi = E_L = E_\phi = \mathbf{440 \text{ V}}$
c. $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{220 \Omega} = \mathbf{2 \text{ A}}$ d. $I_L = \sqrt{3} I_\phi = (1.732)(2 \text{ A}) = \mathbf{3.464 \text{ A}}$
26. a, b. The same as problem 24.
c. $Z_\phi = 22 \Omega \angle 0^\circ \parallel 22 \Omega \angle 90^\circ = 15.56 \Omega \angle 45^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{440 \text{ V}}{15.56 \Omega} = \mathbf{28.28 \text{ A}}$
d. $I_L = \sqrt{3} I_\phi = (1.732)(28.28 \text{ A}) = \mathbf{48.98 \text{ A}}$
28. a. $\theta_2 = -120^\circ, \theta_3 = +120^\circ$
b. $V_{ab} = 100 \text{ V} \angle 0^\circ, V_{bc} = 100 \text{ V} \angle -120^\circ, V_{ca} = 100 \text{ V} \angle 120^\circ$
c. —
d. $Z_\phi = 12 \Omega + j16 \Omega = 20 \Omega \angle 53.13^\circ$
 $I_{ab} = \frac{V_{ab}}{Z_{ab}} = \frac{100 \text{ V} \angle 0^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle -53.13^\circ}$
 $I_{bc} = \frac{V_{bc}}{Z_{bc}} = \frac{100 \text{ V} \angle -120^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle -173.13^\circ}$
 $I_{ca} = \frac{V_{ca}}{Z_{ca}} = \frac{100 \text{ V} \angle 120^\circ}{20 \Omega \angle 53.13^\circ} = \mathbf{5 \text{ A} \angle 66.87^\circ}$
e. $I_{Aa} = I_{Bb} = I_{Cc} = \sqrt{3} I_\phi = (1.732)(5 \text{ A}) = \mathbf{8.66 \text{ A}}$
30. $P_T = 3I_\phi^2 R_\phi = 3(6 \text{ A})^2 12 \Omega = \mathbf{1296 \text{ W}}$
 $Q_T = 3I_\phi^2 X_\phi = 3(6 \text{ A})^2 16 \Omega = \mathbf{1728 \text{ VAR}(C)}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{2160 \text{ VA}}$
 $F_p = \frac{P_T}{S_T} = \frac{1296 \text{ W}}{2160 \text{ VA}} = \mathbf{0.6 \text{ (leading)}}$
32. $P_T = 3I_\phi^2 R_\phi = 3(8.98 \text{ A})^2 10 \Omega = \mathbf{2419.21 \text{ W}}$
 $Q_T = 3I_\phi^2 X_\phi = 3(8.98 \text{ A})^2 10 \Omega = \mathbf{2419.21 \text{ VAR}(C)}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3421.28 \text{ VA}}$

$$F_p = \frac{P_T}{S_T} = \frac{2419.21 \text{ W}}{3421.28 \text{ VA}} = \mathbf{0.7071 \text{ (leading)}}$$

34. $P_T = 3I_\phi^2 R_\phi = 3(1.471 \text{ A})^2 100 \Omega = \mathbf{649.15 \text{ W}}$
 $Q_T = 3I_\phi^2 X_\phi = 3(1.471 \text{ A})^2 100 \Omega = \mathbf{649.15 \text{ VAR(C)}}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{918.04 \text{ VA}}$
 $F_p = \frac{P_T}{S_T} = \frac{649.15 \text{ W}}{918.04 \text{ VA}} = \mathbf{0.7071 \text{ (leading)}}$

36. $P_T = 3 \frac{V_\phi^2}{R_\phi} = \frac{3(120.1 \text{ V})^2}{15 \Omega} = \mathbf{2884.80 \text{ W}}$
 $Q_T = 3 \frac{V_\phi^2}{X_\phi} = \frac{3(120.1 \text{ V})^2}{20 \Omega} = \mathbf{2163.60 \text{ VAR(C)}}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3605.97 \text{ VA}}$
 $F_p = \frac{P_T}{S_T} = \frac{2884.80 \text{ W}}{3605.97 \text{ VA}} = \mathbf{0.8 \text{ (leading)}}$

38. $P_T = 3 \frac{V_\phi^2}{R_\phi} = \frac{3(440 \text{ V})^2}{22 \Omega} = \mathbf{26.4 \text{ kW}}$
 $Q_T = P_T = \mathbf{26.4 \text{ kVAR(L)}}$
 $S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{37.34 \text{ kVA}}$
 $F_p = \frac{P_T}{S_T} = \frac{26.4 \text{ kW}}{37.34 \text{ kVA}} = \mathbf{0.707 \text{ (lagging)}}$

40. $P_T = \sqrt{3} E_L I_L \cos \theta$
 $4800 \text{ W} = (1.732)(200 \text{ V}) I_L (0.8)$
 $I_L = 17.32 \text{ A}$
 $I_\phi = \frac{I_L}{\sqrt{3}} = \frac{17.32 \text{ A}}{1.732} = 10 \text{ A}$
 $\theta = \cos^{-1} 0.8 = 36.87^\circ$
 $Z_\phi = \frac{V_\phi}{I_\phi} = \frac{200 \text{ V} \angle 0^\circ}{10 \text{ A} \angle -36.87^\circ} = 20 \Omega \angle 36.87^\circ = \mathbf{16 \Omega + j12 \Omega}$

42. $\Delta: Z_\phi = 15 \Omega + j20 \Omega = 25 \Omega \angle 53.13^\circ$
 $I_\phi = \frac{V_\phi}{Z_\phi} = \frac{125 \text{ V}}{25 \Omega} = 5 \text{ A}$
 $P_T = 3I_\phi^2 R_\phi = 3(5 \text{ A})^2 15 \Omega = \mathbf{1125 \text{ W}}$
 $Q_T = 3I_\phi^2 X_\phi = 3(5 \text{ A})^2 20 \Omega = \mathbf{1500 \text{ VAR(L)}}$

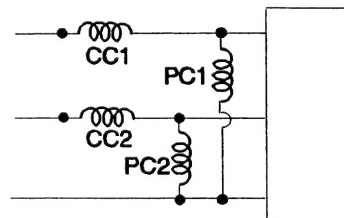
$$\begin{aligned}
 Y: \quad V_\phi &= V_L / \sqrt{3} = 125 \text{ V} / 1.732 = 72.17 \text{ V} \\
 Z_\phi &= 3 \Omega - j4 \Omega = 5 \Omega \angle -53.13^\circ \\
 I_\phi &= \frac{V_\phi}{Z_\phi} = \frac{72.17 \text{ V}}{5 \Omega} = 14.43 \text{ A} \\
 P_T &= 3I_\phi^2 R_\phi = 3(14.43 \text{ A})^2 3 \Omega = 1874.02 \text{ W} \\
 Q_T &= 3I_\phi^2 X_\phi = 3(14.43 \text{ A})^2 4 \Omega = 2498.7 \text{ VAR} \\
 P_T &= 1125 \text{ W} + 1874.02 \text{ W} = 2999.02 \text{ W} \\
 Q_T &= 1500 \text{ VAR}(L) - 2498.7 \text{ VAR}(C) = 998.7 \text{ VAR}(C) \\
 S_T &= \sqrt{P_T^2 + Q_T^2} = 3161 \text{ VA} \\
 F_p &= \frac{P_T}{S_T} = \frac{2999.02 \text{ W}}{3161 \text{ VA}} = 0.949 \text{ (leading)}
 \end{aligned}$$

44. a. —

$$\begin{aligned}
 b. \quad V_\phi &= \frac{220 \text{ V}}{\sqrt{3}} = 127.02 \text{ V}, Z_\phi = 10 \Omega - j10 \Omega = 14.14 \Omega \angle -45^\circ \\
 I_\phi &= \frac{V_\phi}{Z_\phi} = \frac{127.02 \text{ V}}{14.14 \Omega} = 8.98 \text{ A} \\
 P_T &= 3I_\phi^2 R_\phi = 3(8.98 \text{ A})^2 10 \Omega = 2419.2 \text{ W} \\
 \text{Each wattmeter: } &\frac{2419.2 \text{ W}}{3} = 806.4 \text{ W}
 \end{aligned}$$

46. a. —

$$\begin{aligned}
 b. \quad P_T &= P_\ell + P_h = 85 \text{ W} + 200 \text{ W} = 285 \text{ W} \\
 c. \quad 0.2 &\Rightarrow \frac{P_\ell}{P_h} = 0.5 \\
 P_h &= \frac{P_\ell}{0.5} = \frac{100 \text{ W}}{0.5} = 200 \text{ W} \\
 P_T &= P_h - P_\ell = 200 \text{ W} - 100 \text{ W} = 100 \text{ W}
 \end{aligned}$$



$$\begin{aligned}
 48. \quad a. \quad I_{ab} &= \frac{E_{AB}}{R \angle 0^\circ} = \frac{208 \text{ V} \angle 0^\circ}{10 \Omega \angle 0^\circ} = 20.8 \text{ A} \angle 0^\circ \\
 I_{bc} &= \frac{E_{BC}}{R \angle 0^\circ} = \frac{208 \text{ V} \angle -120^\circ}{10 \Omega \angle 0^\circ} = 20.8 \text{ A} \angle -120^\circ \\
 I_{ca} &= \frac{E_{CA}}{R \angle 0^\circ} = \frac{208 \text{ V} \angle 120^\circ}{10 \Omega \angle 0^\circ} = 20.8 \text{ A} \angle 120^\circ \\
 b. \quad I_{Aa} + I_{ca} - I_{ab} &= 0 \\
 I_{Aa} &= I_{ab} - I_{ca} \\
 &= 20.8 \text{ A} \angle 0^\circ - 20.8 \text{ A} \angle 120^\circ \\
 &= 20.8 \text{ A} - (-10.4 \text{ A} + j18.01 \text{ A}) \\
 &= 31.2 \text{ A} - j18.01 \text{ A} \\
 &= 36.02 \text{ A} \angle -30^\circ \\
 I_{Bb} + I_{ab} - I_{bc} &= 0
 \end{aligned}$$

$$\begin{aligned}
\mathbf{I}_{Bb} &= \mathbf{I}_{bc} - \mathbf{I}_{ab} \\
&= 20.8 \text{ A } \angle -120^\circ - 20.8 \text{ A } \angle 0^\circ \\
&= (-10.4 \text{ A} - j18.01 \text{ A}) - 20.8 \text{ A} \\
&= -31.2 \text{ A} - j18.01 \text{ A} \\
&= \mathbf{36.02 \text{ A } \angle -150^\circ} \\
\mathbf{I}_{Cc} + \mathbf{I}_{bc} - \mathbf{I}_{ca} &= 0 \\
\mathbf{I}_{Cc} &= \mathbf{I}_{ca} - \mathbf{I}_{bc} \\
&= 20.8 \text{ A } \angle 120^\circ - 20.8 \text{ A } \angle -120^\circ \\
&= (-10.4 \text{ A} + j18.01 \text{ A}) - (-10.4 \text{ A} - j18.01 \text{ A}) \\
&= -10.4 \text{ A} + 10.4 \text{ A} + j18.01 \text{ A} + j18.01 \text{ A} \\
&= \mathbf{32.02 \text{ A } \angle 90^\circ}
\end{aligned}$$

$$\begin{aligned}
\text{c. } P_1 &= V_{ac} I_{Aa} \cos \theta_{V_{ac} I_{Aa}}, \quad V_{ac} = V_{ca} \angle \theta - 180^\circ = 208 \text{ V } \angle 120^\circ - 180^\circ \\
&= 208 \text{ V } \angle -60^\circ \\
&\quad \mathbf{I_{Aa} = 36.02 \text{ A } \angle -30^\circ} \\
&= (208 \text{ V})(36.02 \text{ A}) \cos 30^\circ \\
&= \mathbf{6488.4 \text{ W}} \\
P_2 &= V_{bc} I_{Bb} \cos \theta_{V_{bc} I_{Bb}}, \quad V_{bc} = 208 \text{ V } \angle -120^\circ, \mathbf{I_{Bb} = 36.02 \text{ A } \angle -150^\circ} \\
&= (208 \text{ V})(36.02 \text{ A}) \cos 30^\circ \\
&= \mathbf{6488.4 \text{ W}} \\
\text{d. } P_T &= P_1 + P_2 = 6488.4 \text{ W} + 6488.4 \text{ W} \\
&= \mathbf{12,976.8 \text{ W}}
\end{aligned}$$

$$\begin{aligned}
50. \quad \mathbf{Z_1} &= 12 \Omega - j16 \Omega = 20 \Omega \angle -53.13^\circ, \mathbf{Z_2} = 3 \Omega + j4 \Omega = 5 \Omega \angle 53.13^\circ \\
\mathbf{Z_3} &= 20 \Omega \angle 0^\circ
\end{aligned}$$

$$\begin{aligned}
\mathbf{E_{AB}} &= 200 \text{ V } \angle 0^\circ, \mathbf{E_{BC}} = 200 \text{ V } \angle -120^\circ, \mathbf{E_{CA}} = 200 \text{ V } \angle 120^\circ \\
\mathbf{Z_\Delta} &= \mathbf{Z_1 Z_2} + \mathbf{Z_1 Z_3} + \mathbf{Z_2 Z_3} \\
&= (20 \Omega \angle -53.13^\circ)(5 \Omega \angle 53.13^\circ) + (20 \Omega \angle -53.13^\circ)(20 \Omega \angle 0^\circ) \\
&\quad + (5 \Omega \angle 53.13^\circ)(20 \Omega \angle 0^\circ) \\
&= 100 \Omega \angle 0^\circ + 400 \Omega \angle -53.13^\circ + 100 \Omega \angle 53.13^\circ \\
&= 100 \Omega + (240 \Omega - j320 \Omega) + (60 \Omega + j80 \Omega) \\
&= 400 \Omega - j240 \Omega \\
&= 466.48 \Omega \angle -30.96^\circ \\
\mathbf{I_{an}} &= \frac{\mathbf{E_{AB} Z_3} - \mathbf{E_{CA} Z_2}}{\mathbf{Z_\Delta}} = \frac{(200 \text{ V } \angle 0^\circ)(20 \Omega \angle 0^\circ) - (200 \text{ V } \angle 120^\circ)(5 \Omega \angle 53.13^\circ)}{\mathbf{Z_\Delta}} \\
&= \frac{4000 \text{ A } \angle 0^\circ - 1000 \text{ A } \angle 173.13^\circ}{466.48 \angle -30.96^\circ} = \mathbf{10.706 \text{ A } \angle 29.59^\circ} \\
\mathbf{I_{bn}} &= \frac{\mathbf{E_{BC} Z_1} - \mathbf{E_{AB} Z_3}}{\mathbf{Z_\Delta}} = \frac{(200 \text{ V } \angle -120^\circ)(20 \Omega \angle -53.13^\circ) - (200 \text{ V } \angle 0^\circ)(20 \Omega \angle 0^\circ)}{\mathbf{Z_\Delta}} \\
&= \frac{4000 \text{ A } \angle -173.13^\circ - 4000 \text{ A } \angle 0^\circ}{466.48 \angle -30.96^\circ} = \mathbf{17.12 \text{ A } \angle -145.61^\circ} \\
\mathbf{I_{cn}} &= \frac{\mathbf{E_{CA} Z_2} - \mathbf{E_{BC} Z_1}}{\mathbf{Z_\Delta}} = \frac{(200 \text{ V } \angle 120^\circ)(5 \Omega \angle 53.13^\circ) - (200 \text{ V } \angle -120^\circ)(20 \Omega \angle -53.13^\circ)}{\mathbf{Z_\Delta}} \\
&= \frac{1000 \text{ A } \angle 173.13^\circ - 4000 \text{ A } \angle -173.13^\circ}{466.48 \angle -30.96^\circ} = \mathbf{6.512 \text{ A } \angle 42.32^\circ}
\end{aligned}$$

$$\begin{aligned}
 P_T &= I_{\text{an}}^2 12 \, \Omega + I_{\text{bn}}^2 3 \, \Omega + I_{\text{cn}}^2 20 \, \Omega \\
 &= (10.706 \, \text{A})^2 12 \, \Omega + (17.119 \, \text{A})^2 3 \, \Omega + (6.512 \, \text{A})^2 20 \, \Omega \\
 &= 1375.42 \, \text{W} + 879.18 \, \text{W} + 848.12 \, \text{W} = \mathbf{3102.72 \, \text{W}}
 \end{aligned}$$

$$\begin{aligned}
 Q_T &= I_{\text{an}}^2 X_C + I_{\text{bn}}^2 X_L = (10.706 \, \text{A})^2 16 \, \Omega + (17.119 \, \text{A})^2 4 \, \Omega \\
 &= 1833.9 \, \text{VAR} + 1172.24 \, \text{VAR} = 661.66 \, \text{VAR} \\
 &\quad \quad \quad (C) \quad \quad \quad (L) \quad \quad \quad (C)
 \end{aligned}$$

$$S_T = \sqrt{P_T^2 + Q_T^2} = \mathbf{3172.49 \, \text{VA}}$$

$$F_p = \frac{P_T}{S_T} = \frac{3102.72 \, \text{W}}{3172.49 \, \text{VA}} = \mathbf{0.978 \, (\text{leading})}$$